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DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Laying an Underwater Pipeline from a Floating Vessel

We, SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ N.V., a Company organised under the Laws of The Netherlands, of 30, Carel van Bylandtlaan, The Hague, The Netherlands, do hereby declare the invention, for which we pray that a patent may be performed, to be particularly described in and by the following statement:—

This invention relates to the laying of a pipeline on the floor of a body of water from a vessel floating on the water.

When laying pipeline along the floor of a deep body of water, the problem of avoiding pipeline kinking and excessive bending while staying within the stress limits of the pipeline is ever present and difficult to overcome. This problem results from the fact that very long continuous lengths of pipeline, typically ranging in hundreds of metres, must be lowered from the surface of the body of water to the floor thereof and that controlled movement of such lengths is very difficult. Various systems have been devised to facilitate control of the long lengths of pipeline during the laying thereof in deep bodies of water. Typically, these devices employ extensive guide structures at both the laybarge end of the pipeline and the floor of the body of water, which guide structures function to support the pipeline and control the movement and bending thereof. As additions or alternatives to these guide structures, buoyant elements have also often been used to support pipeline being laid.

The aforementioned prior methods have the shortcoming that they generally necessitate a start and stop laying operation, since relocation of the supporting guide or buoyant means is often required periodically as the pipeline was laid. In the prior systems interruptions are also encountered under adverse laying conditions resulting from wind or wave action which affect the locating of the extensive guide and buoyancy means. The use of extensive guide structures is extremely expensive, since the structures must be fabricated to sustain very high loads. Furthermore, such structures are very susceptible to damage under adverse weather conditions where precise control of the lay-barge is impossible.

The foregoing pipe laying systems also often prove ineffective in controlling the direction in which the pipeline is laid and the stresses occurring at the point were the pipeline first touches the floor of the body of water. Direction control is difficult due to the susceptibility of the guide or buoyancy means to uncontrolled movement by wind or wave forces. The control of pipeline bending at the first point it touches the floor proves difficult in the prior systems due to irregularities in the floor of the body of water and inadvertent backup of the barge or boat being used to lay the pipeline.

It is, accordingly, the object of this invention to provide a method for laying pipeline along the floor of a deep body of water while avoiding the shortcomings of prior systems, such as those discussed above.

According to the present invention a method of laying a pipeline on the floor of a body of water from a vessel floating on said body comprises:—

(a) anchoring one end of the pipeline to the floor of the body of water;

(b) moving the vessel in the direction it is desired to lay the pipeline and paying out the pipeline from the vessel;

(c) controlling the paying out of the pipeline and movement of the vessel to hold the tension on the pipeline within a preselected range sufficient to maintain the bending and axial stresses in the pipeline at a permissible level;

(d) terminating the pipeline on the vessel at the length thereof desired to be laid, thus forming another end;

(e) securing a drawline between said other end of the pipeline and the vessel; and

(f) paying out the drawline to lower said other end of the pipeline to the floor of the body of water, the paying out of the

drawline being controlled to hold the tension on the pipeline within a predetermined range sufficient to maintain the bending and axial stresses in the pipeline at a permissible level.

Through continually controlling the tension on the pipeline being laid, excessive bending and kinking of the pipeline is avoided without the necessity of extensive support structures or buoyant support means. At the same time, accurate control of the direction in which the pipeline is being laid is effected.

In actual practice of the invention, the laying vessel may take substantially any form, such as a non-propelled barge moved by a tug or other auxiliary propulsion means or a self-propelled boat. The tension applied to the pipeline during laying may be controlled through the propulsion of the laying vessel and tension controlling means on the apparatus used to pay out the pipeline. The method can be carried out either continuously or at interrupted intervals as dictated largely by the propulsion means for the lay vessel and the pipeline storage and handling means provided thereon. For example, in a preferred embodiment of the invention the pipeline is stored on a reel which provides both for the controlled tension applied to the pipeline and the continuous paying out of the pipeline.

The invention may be carried into practice in various ways but certain specific embodiments will now be described with reference to the accompanying drawings, wherein:

Figure 1 to 5 illustrate, in sequence, the steps required in one application of the invention for laying the pipeline from a horizontally positioned reel on the vessel;

Figure 6 to 10 illustrate in sequence the steps involved in another application of the invention wherein a self-propelled lay vessel having a derrick is utilized;

Figure 11 illustrates a lay-vessel suitable for laying out the pipeline as a continuous string from a vertically positioned reeling mechanism on the vessel;

Figure 12 illustrates a lay-vessel with a modified guide structure for directing pipeline into the water;

Figure 13 illustrates exemplary operating curves indicating the operating characteristics encountered in the application of the present invention for four particular pipelines which are limited to certain maximum stresses, and

Figure 14 diagrammatically illustrates vessel and pipeline positions illustrative of the characteristics denoted in Figure 13.

Figure 1 illustrates a lay-barge 10 of the non-propelled type having a tow line 11 extending to a tug (not illustrated). The lay-barge 10 is provided on the deck thereof with pipe handling apparatus including a reeling mechanism 12 having a continuous pipeline 13 wound therearound, which reeling mechanism is provided with control means to regulate both the rate and the tension at which the pipeline 13 is paid out therefrom. A straightening mechanism 14 is located on the deck of the barge 10 adjacent to the reeling mechanism 12 and provides means whereby the pipeline paid out from the mechanism is straightened prior to the time it is directed off of the lay-barge. The lay-barge 10 also includes a conventional anchor line 15 at the rear thereof provided with suitable actuating means and a winch 16 adapted to pay out a second anchor line or draw line 17 for reasons which will become more apparent in the subsequent description. The rear of the barge is provided with a supporting structure or "stinger" 20 adapted to control the curvature of the anchor line 17 or pipeline 13 as they are directed off the rear of the barge.

The lay-barge 10 and the elements cooperating therewith are also seen in Figures 2 to 5. The elements appearing in each of these figures only differ with respect to the positions they assume in the various steps of the sequence depicted by the figures.

In Figures 1 to 5, the lay-barge 10 is shown floating on a body of water 21 having a floor 22. On the floor 22 are positioned a wellhead 23 and a gathering facility 24 between which it is desired to lay the pipeline 13. It is noted that the wellhead and gathering facility are spaced apart by a distance so large that they cannot both be illustrated in a single figure of a practical scale. Accordingly, the wellhead 23 only appears in Figures 1 to 3 and the facility 24 only appears in Figures 4 and 5. The appearance of the wellhead and facility in the respective figures results from the fact that the figures depict the barge 10 as it moved from the vicinity of the wellhead 23 to the vicinity of the facility 24.

The wellhead 23 may take substantially any form adapted to have the end of the pipeline 13 secured thereto, and therefore it is to be understood that the method of the present invention is not limited to use in extending pipelines between any particular types of underwater installations. The facility 24 may also take substantially any form adapted to have the end of a pipeline secured thereto.

Referring now to the application of the invention illustrated in Figures 1 to 5, the initial stage of operation is shown in Figure 1. In this stage, the barge 10 is first positioned near the wellhead 23. It is noted that the degree to which the barge is initially spaced from the wellhead is determined so that the first lowered end of the pipeline 13 will touch down on the bottom 22 in the close vicinity of the wellhead 23. The exact degree to which the barge is initially spaced from the wellhead 23 is dictated by the depth of the body of water and the physical characteristics of the pipeline being laid.

Upon positioning the barge 10 to one side of the wellhead 23, the anchor line 15 is

lowered vertically from the barge so that the anchor thereon securely engages the floor 22. After lowering of the anchor line 15, the barge 10 is moved in the direction it is desired to lay the pipe until the line 15 assumes a position wherein the forces imparted to the barge by the line 15 and the tow line 11 will be assured of holding the barge 10 on course along the line it is desired to lay the pipeline. In a depth of water of about 150 metres, the movement of the barge 10 required to pay out the anchor line 15 to the desired extent might typically be 1050 metres. After the anchor line 15 has been paid out a sufficient length to maintain the barge on course, a second anchor line 17 is lowered from the barge over the stinger 20 and into engagement with the floor 22. With the anchor lines 15 and 17 in secure engagement with the floor 22, as illustrated in Figure 1, the barge 10 is moved toward the wellhead 23 along the line it is desired to lay the pipeline. During the latter movement, the anchor lines are paid out and assume a position more closely approaching the horizontal. After the barge 10 has been moved toward the wellhead 23 to a predetermined extent, the anchor line 17 is in condition to be utilized as a drawline to pull the pipeline 13 off the barge and into the body of water 21. Typically, in a depth of water of approximately 150 metres the barge movement between the lowering the line 17 and the commencement of lowering of the pipeline 13 might be in the order of 750 metres. As will become apparent subsequently, the exact extent of the latter movement will be dependent on the physical characteristics of the pipeline being laid, the depth of the water and the position of the barge with respect to the wellhead 23. The latter characteristic is particularly important, since the first lowered end of the pipeline 13 should preferably touch down on the floor 22 in the very close vicinity of the wellhead 23.

After the pipeline 13 has been secured to the drawline 17, movement of the barge 10 is continued in the direction it is desired to lay the pipeline and the anchor line 15 and pipeline 13 are continuously and selectively paid out from the barge. The tension held on the anchor line 15 is sufficient to maintain the barge 10 on its course and to prevent barge gaining, and the tension held on the pipeline 13 is sufficient to maintain the pipeline in a relatively straight condition wherein the bending and axial stresses applied thereto are maintained below the permissible maximum value thereof. It is also possible to use an additional means, such as auxiliary propulsion engine, to assist in maintaining the barge on location. The exact amount of tension maintained on the pipeline and the degree to which this tension may be varied without exceeding the maximum stresses is capable of being ascertained, as will be described subsequently with respect to a specific example of the invention. These stresses are chosen so that the pipeline is not excessively bent, stretched or kinked during the laying operation. The tension applied to the pipeline 13 is controlled by the operation of the reeling mechanism 12. It is noted that reeling mechanisms, such as 12, are ideally suited to control tension, since the tension required to unwind lines would therearound may be readily controlled, as is well known in the art.

Figure 3 illustrates the barge 10 while the first lowered end of the pipeline 13 is being lowered in the vicinity of the wellhead 23 and the barge is moving towards the facility 24. During and subsequent to this time, the tension on the pipeline 13 is maintained within a preselected range to limit bending and axial stresses to which the line is subjected at a permissible level.

Figures 4 and 5 illustrate the barge 10 and pipeline 13 after an amount of pipeline has been paid out sufficient to span the distance between the wellhead 23 and facility 24. When this point is first reached, as illustrated in Figure 4, the pipeline 13 is terminated and a second drawline or lowering line 25 is secured to the free end thereof. Once the drawline 25 is secured to the pipeline 13, movement of the barge 10 is continued, as illustrated in Figure 5 until the end of the pipeline 13 secured to the drawline 25 assumes a position on the floor 22. During movement of the barge 10 from the position shown in Figure 4 to that shown in Figure 5, both the anchor line 15 and drawline 25 are paid out, with the tension maintained on the line 15 being held sufficient to maintain the barge on course and the tension on the line 25 being maintained wihin a preselected range to limit the stresses applied to the pipeline. The tension applied on the lines 15 and 25, respectively, are each controlled by the operation of a corresponding winch. The tension required to unwind a line wound on a winch may be readily controlled, as is well known in the art.

After the pipeline 13 has been laid between the wellhead 23 and facility 24, the drawlines 17 and 25 may be removed therefrom and the anchor line 15 may be retrieved, since the laying operation is complete. At this point, supplementary means may be utilized to draw the ends of the pipeline 13 into engagement with the wellhead 23 and facility 24. The pipeline 13 should be long enough to facilitate its connection to the wellhead and facility through any desired means, and such means might be activated either remotely or through the use of divers. Likewise, the removal of the drawlines 17 and 25 may be carried out either remotely or through the use of divers.

Referring now to the sequence drawings of Figures 6 to 10, these, illustrate an alternative arrangement for carrying out the method of the present invention. The arrangement of

these differs from that described previously with respect to Figures 1 to 5 primarily in that it includes provisions to facilitate the engagement of the pipeline being laid with the installations between which it is extended. In addition to this principal difference, the lay-barge and its associated apparatus illustrated in the sequence of Figures 6 to 10 differs from that shown in Figures 1 to 5. The latter difference is intended merely to show that the method of the present invention can be practised with varying apparatuses. Specifically, the method as shown in Figures 6 to 10 is practised with a self-propelled barge provided with automatic ship positioning means and with a pipeline lowering derrick rather than a reel.

Referring now to Figure 6, this illustrates a wellhead 26 provided with outrigger arm 27 carrying a pipeline receiving alignment tube 30. The wellhead 26 is positioned on the floor 31 of a body of water 32. As illustrated, the alignment tube 30 has extending therethrough a drawline 33 having one end supported by marker buoy 34 and the other end secured to an anchor 35 disposed on the floor 31. The anchor 35 is, in turn, secured to a crown line 36 supported by a marker buoy 37. For all practical purposes the lines 33 and 36 can be considered one continuous line, since they are both secured to the anchor 35.

Figure 7 illustrates the wellhead structure described with reference to Figure 6 as it is being used to facilitate the pipeline laying method of the present invention. Corresponding pieces of apparatus are illustrated in the sequence drawings of Figures 6 to 10. In Figure 7, a self-propelled lay-barge 40 is shown positioned above and to one side of the wellhead 26 in the initial stage of the laying operation. The barge 40 includes propulsion propellers 41 to control movement of the barge and a tilt-meter line 42 adapted to be extended to the floor of the body of water at a point near where it is desired to position the barge. The tilt-meter line co-operates with a control mechanism on the barge to activate the propellers 41 and maintain the barge automatically and dynamically over the preselected position.

The structure on the barge 40 includes a derrick 44 disposed above an opening 45 extending through the centre of the barge into communication with the body of water therebelow. Within the well 45 and directly therebelow is disposed a guide or "stinger" 46 adapted to guide and limit the bending radius of lines extending therethrough. The derrick 44 is located so as to be adapted to lower pipelines through the opening 45. These pipelines would typically be assembled from sections as they are fed through the opening 45. Thus a continuous line is formed with one end thereof supported by the derrick, for example by a travelling block 47 therein. The travelling block 47 is supported through cables 50 which are adapted to raise and lower the block and to some extent control the amount of tension imparted to the pipeline suspending therefrom.

Figure 7 also illustrates a draw-barge 38 of similar construction to the barge 40 and having provided thereon a winch 43 adapted to be secured to lines extending through the opening 39 in the barge.

In operation of the application of the invention illustrated in Figure 7, the lay-barge 40 is first positioned over the location where it is desired to commence laying through means of the previously described tilt-meter line 42 and its co-operating positioning equipment. At about the same time, the draw-barge 38 is positioned above the wellhead 26 through any suitable means. The end of the drawline 33 secured to the marker buoy 34 is then engaged on the winch 43 of the barge 38 and the other end of the drawline is pulled up through the opening 45 of the barge 40. The latter operation is accomplished by pulling the crown line 36 and the anchor 35, along with the drawline 33 secured thereto, to the barge 40. After the drawline 33 is pulled through the opening 45, a pipeline 51, having one end supported by the travelling block 47, is secured to the end of the drawline 33 previously secured to the anchor 35.

With the pipeline 51 secured to the drawline 33, laying of the pipeline is commenced by applying tension to the drawline 33 through the winch 43. This tension functions to draw the pipeline toward the wellhead 26 is illustrated in Figure 7. During drawing of the pipeline 51 through the opening 45, sections of pipe are continuously added thereto at the derrick 44. The stinger 46 limits the bend radius assumed by the pipeline as it departs from the barge 40 and the tension applied to the drawline through the winch 43 is controlled so as to maintain the bending and axial stresses applied to the pipeline at a permissible level. This tension is chosen so that the pipeline is not exceedingly bent, kinked or stretched during the laying operation. It is noted that in the initial condition illustrated in Figure 1, the barge 40 is located relative to the wellhead 26 so that the pipeline 51 may be pulled into a position closely adjacent the wellhead without requiring movement of the barge 40. The exact positioning of the barge can be readily determined by knowing the depth of water and the angle at which the pipeline departs from the barge.

After the pipeline 51 has been pulled closely adjacent to the wellhead 26, as illustrated in Figure 7, the barge 40 is moved in the direction it is desired to lay the pipeline, while paying out the pipeline, until at least a portion of the pipeline assumes a position tangent to the floor 31. During this initial movement of the barge 40, the tension maintained on the pipeline is controlled to limit the stresses applied

to the pipeline. The tension applied to the pipeline is controlled by a suitable reeling mechanism or winch. It is noted that a reeling mechanism or a winch is ideally suited to control tension, since the tension required to unwind a line wound therearound may be readily controlled, as is well known in the art. Upon approaching the wellhead 26 the forward end of the pipeline is drawn by the drawline into engagement with the alignment tube 30. Naturally, as the pipeline 51 is being drawn into the alignment tube 30 the tension applied thereto at the barge end is maintained to control the stresses applied to the pipeline.

After the pipeline 51 has been drawn into engagement with the alignment tube 30, the first drawline 33 and the tilt-meter line 42 are disconnected from the pipeline 51 and floor 31, respectively, and retrieved. At this point continued laying of the pipeline 51 may be carried out in a manner as described with respect to the pipeline 13 in the figures 1 to 5 sequence. Specifically, continued laying of the pipeline 51 is accomplished by moving the barge 40 in the direction it is desired to lay the pipeline while paying out the pipeline, as illustrated in Figure 8. During movement of the barge 40, a predetermined horizontal tension in the pipeline is maintained by exerting a constant thrust on the main propulsion screws of the barge. The effects of currents, waves, and winds on the horizontal tension exerted by the barge are checked by periodic measurements of the pipe shape, and corrections in propulsion efforts are made as required. Alternatively, the propulsion units are controlled to provide a constant horizontal thrust on the pipeline as measured by strain gauges at the stinger 46. The thrust can also be controlled in response to measurements of the angle of departure of the pipeline from the barge, as will become apparent from the example given later.

Figure 9 illustrates an underwater installation 52, such as a storage facility, located on the floor 31 of the body of water 32. The installation 52 is shown as being provided with a plurality of alignment tubes 53, corresponding to the previously described tubes 30.

In operation, when the barge 40 approaches the installation 52 to which it is desired to connect the pipeline 51, the pipeline is terminated at a length which permits the terminated end thereof to be lowered to the installation 52. Actually, as will be described subsequently with respect to Figure 10, the pipeline is lowered to one side of the installation and subsequently drawn into engagement therewith. After being terminated at the desired length, the terminated end of the pipeline is secured to one end of a drawline 54 and to the end of a lowering line 55 extending through the opening 45 in the barge. It is to be understood that initially the drawline 54 had its ends secured to buoys corresponding to the buoys 34 and 37 illustrated in Figure 6. The lowering line 55 is secured to suitable tension means, such as a winch (not illustrated) on the barge 40. Before, or after, the one end of the drawline 54 is secured to the pipeline 51, the other end of the drawline is operatively secured to a winch 58 on the barge 40. With the pipeline 51, drawline 54 and lowering line 55 so disposed, the barge 40 is located above the installation 52 in a position wherein the pipeline 51 may be lowered closely adjacent and to one side of the installation 52. The barge is maintained in the latter position by lowering the tilt-meter line 42 into engagement with the floor 31 and operating the automatic positioning equipment co-operating therewith. At this point the pipeline 51 is lowered to the floor 31 by paying out the lowering line 55 and reeling in the drawline 54. During the lowering of the pipeline, the drawline 54 is maintained in a substantially slack condition so as not to affect the positioning of the pipeline, whereas the lowering line 55 is maintained under sufficient tension to control the stresses applied to the pipeline.

Figure 10 illustrates the barge 40 and installation 52 after the pipeline 51 has been lowered to the floor 31 and the lowering line 55 has been disconnected therefrom. In this condition, the pipeline 51 may be drawn into engagement with the alignment tube 53 by simply applying tension to the drawline 54. This tension functions to move the pipeline 51 from the solid line position illustrated into the dotted line position. At least a portion of the alignment tube 53 is preferably pivotally mounted in order to facilitate its alignment with the end of the pipeline 52. After engagement of the pipeline 51 with the tube 53, the drawline 54 may be removed therefrom by remotely operable means or by means of a diver.

At this point it is noted that the purpose of initially laying the pipeline 51 to one side of installation 52 was to facilitate engagement of the pipeline in the alignment tube 53. This procedure is necessary because, as a practical matter, it is very difficult, if not impossible to cut the pipeline to a length where it may be drawn directly to the installation. The difficulty in cutting the pipeline to exact length is avoided by drawing the line to one side of the installation, since the line may then be pulled to the installation in a gently sweeping curve, as illustrated by the dashed line in Figure 10. The initial pulling the pipeline to one side of the installation also provides for a degree of slack which facilitates the drawing of the pipeline into the alignment tube 53.

Figure 11 illustrates a self-propelled barge 65 adapted to be used in the application of the invention illustrated in Figures 6 to 10. The barge 56 differs from the previously described barge 40 in that the pipeline handling apparatus comprises a vertically positioned

reeling mechanism 57 rather than a derrick 44 and that it does not include a pipeline "stinger". The use of such a reeling mechanism avoids the necessity of joining sections of pipe as the pipeline is paid out, and tension applied to the pipe may be readily controlled.

The reel of the mechanism 57 functions to limit the bending stresses applied to the pipelines as it departs from the barge and therefore, no stinger is necessary. Although not illustrated, the reeling mechanism is preferably used with the straightening mechanism 14 used with previously described barge 10.

Figure 12 illustrates yet another form of self-propelled barge 60 corresponding substantially to the barge 40 described with reference to Figures 6 to 11. The barge 60 differs from the barge 40 only in that a guide or "stinger" structure 61 is provided which directs a pipeline passing therethrough into the water in a direction close to the vertical rather than the horizontal. The purpose of this difference is to cope with situations wherein it is more desirable to lower pipeline in a substantially vertical direction. The direction in which the pipeline is lowered is dictated by such things as the size of the pipe, the depth of the water and the allowable bending and axial stresses that may be applied to the pipe. Furthermore, situations my occur where, for economical purposes, it is desirable to lower the pipeline in a substantially vertical direction to minimise the tension required to be applied thereto to limit axial and bending stresses applied to the pipeline.

To reiterate for the sake of clarity, it is noted that the barges illustrated in the sequence of Figures 1 to 5, the sequence of Figures 6 to 10, and in Figures 12 and 13 may all be used in the application of the invention. The particular barge chosen for an applicant of the invention will be dictated primarily by availability and economy. For example, situations may occur where it is desirable to use a barge of the type illustrated in the sequence of Figures 1 to 5 in the sequence of Figures 6 to 10. Whether a barge with a substantially horizontally extending stinger or a substantially vertically extending stinger is used will be dictated by the previously discussed factors of: pipeline characteristics; depth of water; and allowable bending and axial stresses.

EXAMPLE

Figure 13 illustrates a set of curves showing the characteristics that four particular pipelines may be permitted to assume subject to their permissible bending and axial stresses when being laid at a known depth, In each of the four cases, the tubing is of the same dimensions, having an outside diameter of 60.3 millimeters (2 3/8th") and a weight of 68.5 grams per centimetre, but the four tubes differ from each other in the maximum permissible bending and axial stresses, since the tubes are made of metal having different mechanical properties. In order to illustrate the relationship between the angle from the horizontal at which the pipeline departs from the vessel, the depth of water and the extent of allowable layout of pipeline (or moveback of the vessel) let it be assumed for the curves of Figure 13 that the initial horizontal tension applied in each case is 4536 kilograms, and the right-hand ordinate designates the corresponding initial angle from the horizontal at which the pipeline in each case departs from the lay-barge or stinger thereon in the various depths of water. The particular depths of water in metres are found on the left-hand ordinate of the curves. As will be appreciated from Figure 14, if the barge remains stationary and the pipe is laid out, or alternatively if the barge moves back without any pipe layout, then the pipe will assume a greater angle of departure from the barge. The abscissa of the curves accordingly designates either the amount of barge moveback, or pipe layout, in metres that is allowable from the initial position without exceeding the maximum permissible bending and axial stresses for the pipeline, and along the side of each of the curves is indicated the corresponding maximum angle of departure of the pipeline from the horizontal.

It will also be appreciated that the horizontal tension decreases with increasing angle of departure of the pipeline from the barge, and with increasing bending and axial stress, and therefore during the laying operation for each type of tube a certain minimum horizontal tension is permissible depending on the maximum allowable stresses for each tubing. Specifically curves A, B, C and D have maximum permissible stresses (bending plus axial) of 316, 562, 914 and 1757 kilograms per square centimetre respectively. The initial horizontal tension for each of the stresses is, as explained above 4536 kilograms and the minimum horizontal permissible so as not to exceed the above maximum stresses is 1360, 454, 227 and 91 kilograms for curves A, B, C and D respectively.

Since tubing A has the lowest permissible maximum stress (bending plus axial), viz. 316 kg/cm^2, and tubing D has the highest permissible maximum stress (bending plus axial), viz. 1757 kg/cm^2, it follows that for the weakest tubing A the horizontal tension should not fall below a relatively high minimum value, viz. not below 1360 kg, whereas for the strongest tubing D the horizontal tension should not fall below relatively low minimum value, viz. not below 91 kg.

An illustrative example applying the curves of Figure 13 is indicated by the dashed lines thereon and the values determined through use of the curves with the example are given below.

Example conditions of pipeline when laying at a depth of 152.5 metres with an initial horizontal tension of 4536 kilograms

Curve	Maximum allowable stress (bending +axial) (kgs/sq. cm)	Minimum permissible horizontal tension (kgs)	Initial angle of departure from horizontal (degrees)	Maximum permissible angle of departure from horizontal (degrees)	Allowable moveback of pipe layout (metres)
D	1757	91	27	80	80
C	914	227	27	72	60
B	562	454	27	62	44
A	316	1360	27	44	18

From the example conditions it can be seen that for a particular depth of water the allowable conditions for the pipeline can be read directly. Specifically it can be seen that, whereas for each type of the tubing A, B, C and D the initial angle with the horizontal is the same, viz. 27° the maximum permissible angle with the horizontal for each type of tubing differs, viz. 44° for the weakest tubing A and 80° for the strongest tubing D. The last mentioned maximum permissible angles correspond to the above-mentioned minimum values of the horizontal tensions.

Figure 14 diagrammatically illustrates the pipeline and barge positions that would be assumed in an application of the invention. In particular, the figure more closely shows the conditions represented by the curves of Figure 13. In Figure 14, a lay-barge 62 is illustrated in solid line in the condition of initial horizontal tension with a pipeline 63 under the initial tension also being shown in solid line. The dashed line extending down from the solid line representation of the barge 62 indicates the position of the pipeline 63 after the maximum permissible layout without barge moveback, as indicated along the lower absciss of Figure 13. The dashed line representation of the barge 62 and the dashed line extending downwardly therefrom indicate the barge and pipeline position, respectively, after permissible moveback without pipe layout, as designated along the lower absciss of Figure 13 and corresponding in dimension to the permissible pipe layout.

The axial tension applied to the pipeline may be measured and controlled in several alternative ways. The most obvious way is simply to measure the axial tension directly on the barge and to control this tension through any suitable means, such as the afore-mentioned reeling mechanism. As an alternative, for any particular angle of pipeline departure from the barge, either the horizontal or vertical component of the tension may be measured on the barge and this component may be related to the axial tension and utilized to control the tension imparted to the pipeline on the barge. In the ltter case, control is effected simply by controlling either the horizontal thrust or vertical force applied to the pipeline at the barge. Horizontal thrust may be controlled through the propulsion screws of the barge and vertical force can be controlled through the pipeline handling means, such as the afore-described derricks and associated structure. As yet another alternative, once pipeline characteristic curves, such as those developed in the foregoing example, have been developed control of tension can be effected by controlling the angle at which the pipeline departs from the lay-barge.

From the foregoing discussion, and particularly the examples of Figures 13 and 14, it is believed to be apparent that the method of the present invention can be practised with some flexibility. Specifically, in a continuous laying process, such as that described with reference to the sequence drawings of Figures 1 to 5 and Figures 6 to 10 respectively, a certain amount of barge moveback is permissible without stressing the pipeline beyond the maximum selected limit. This flexibility is necessary, since wind and wave action, other possible interruptions, and barge movement may make some barge moveback unavoidable. The example also illustrates the flexibility of the invention with respect to the possibility of discontinuous pipe laying. Discontinuous in this sense is meant to apply laying wherein barge movement is interrupted intentionally during laying of the pipeline, as contrasted to continuous barge movement laying procedures.

In the discontinuous laying procedure of this invention employing the curves of Figure 13, the barge is first moved to a position imposing the initial horizontal tension of 4536 kilograms on the pipeline. At this point, the pipeline is paid out from the barge until the tension equals the minimum permissible horizontal tension. Both the amount of pipe layout and the minimum permissible horizontal tension are readily determined from the operating curves illustrated in Figure 13. After the pipeline has

been paid out to the permissible extent, the barge is once again moved to a position wherein the horizontal tension on the pipeline is again equal to the initial horizontal tension. At this point the pipeline is again paid out to the maximum allowable layout condition. Thus, it can be seen that the pipeline laying method of the present invention can be practised by intermittent barge movement and pipeline layout.

The operating curves for the method of the present invention, as exemplified by Figure 13, can be determined either mathematically or experimentally. For example, the method used to predict stresses may use the beam theory equation which considers the rigidity of the pipe to beyond the point of maximum bending where the moment is about equal to zero. At the latter point, rigidity no longer significantly contributes to the shape of the pipeline. From this point to the lay-barge the pipeline assumes a catenary shape, and catenary equations are used for predicting the shape of the upper portion of the line. By combining these two theories an approximate solution can be developed to predict the entire shape of the line. To check the results obtained from the mathematical derivation, tests may be conducted using both laboratory and full scale environments.

WHAT WE CLAIM IS:—

1. A method of laying a pipeline on the floor of a body of water from a vessel floating on said body, said method comprising:
(a) anchoring one end of the pipeline to the floor of the body of water;
(b) moving the vessel in the direction it is desired to lay the pipeline and paying out the pipeline from the vessel;
(c) controlling the paying out of the pipeline and movement of the vessel to hold the tension on the pipeline within a preselected range sufficient to maintain the bending and axial stresses in the pipeline at a permissible level;
(d) terminating the pipeline on the vessel at the length thereof desired to be laid, thus forming another end;
(e) securing a drawline between said other end of the pipeline and the vessel; and
(f) paying out the drawline to lower said other end of the pipeline to the floor of the body of water, the paying out of the drawline being controlled to hold the tension on the pipeline within a predetermined range sufficient to maintain the bending and axial stresses in the pipeline at a permissible level.

2. A method acording to Claim 1, wherein the movement of the vessel in the direction it is desired to lay the pipeline is continuous and the paying out of pipeline during said movement is continuous.

3. A method according to Claim 1, wherein the tension applied to the pipeline at a particular angle of departure from the vessel is maintained by controlling the thrust with which the vessel is propelled.

4. A method acording to Claim 1, wherein the tension applied to the pipeline is maintained by controlling the angle at which the pipeline departs from the vessel.

5. A method according to Claim 1, wherein the pipeline is initially paid out from the vessel in substantially a vertical direction.

6. A method according to Claim 1, wherein the pipeline is initially paid out from the vessel in substantially a horizontal direction.

7. A method according to Claim 1, wherein the pipeline is paid out from the vessel while freely movable at the vessel with respect to the angle of departure between the pipeline and vessel.

8. A method of extending a pipeline into communication with an installation submerged in a body of water and laying the pipeline on the floor of said body from a floating vessel, said method comprising:
(a) extending the intermediate portion of a drawline into sliding engagement with the submerged installation;
(b) extending the ends of said drawline to the surface of said body of water;
(c) securing one end of a pipeline to be laid to one end of the drawline;
(d) controlling paying in the other end of the drawline to hold the tension on the pipeline within a preselected range while paying out the pipeline secured to said one end of the drawline, said amount of tension being sufficient to maintain the bending and axial stresses in the pipeline at a permissible level;
(e) continuing to pay in said other end of the drawline while paying out the pipeline secured to said one end of the drawline until the pipeline is drawn into communication with the installation;
(f) moving the vessel in the direction it is desired to lay the pipeline and paying out the pipeline while holding the tension on the pipeline within a preselected range sufficient to maintain the bending and axial stresses in the pipeline at a permissible level;
(g) terminating the pipeline on the vessel at the length thereof desired to be laid, thus forming another end;
(h) securing a second drawline between said other end of the pipeline and the vessel, and
(i) paying out the second drawline to lower said other end of the pipeline to the floor of the body of water, the paying out of the second drawline being controlled to hold the tension on the pipeline within a preselected range sufficient to maintain

the bending and axial stresses in the pipeline at a permissible level.

9. A method of laying a pipeline on the floor of a body of water from a vessel floating on the water, substantially as described with reference to the accompanying drawings.

KILBURN & STRODE,
Chartered Patent Agents,
Agents for the Applicants.

Reference has been directed in pursuance of Section 9, sub-section (1) of the Patents Act, 1949, to patent No. 1016439.

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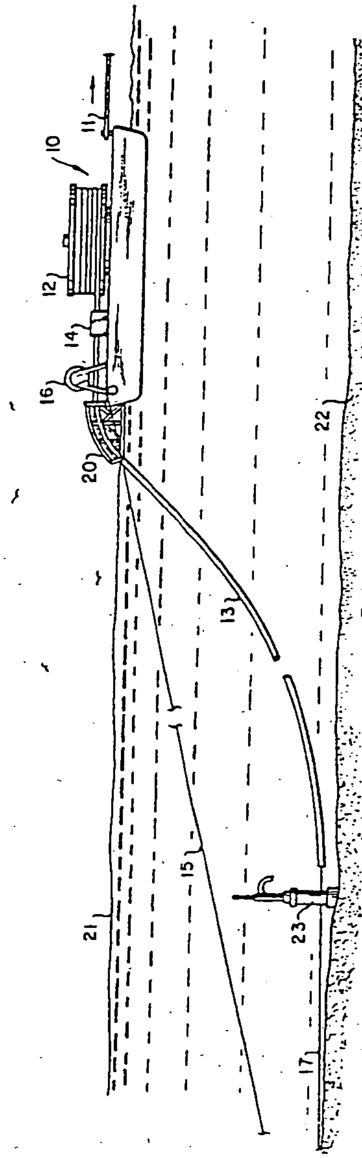

FIG. 3

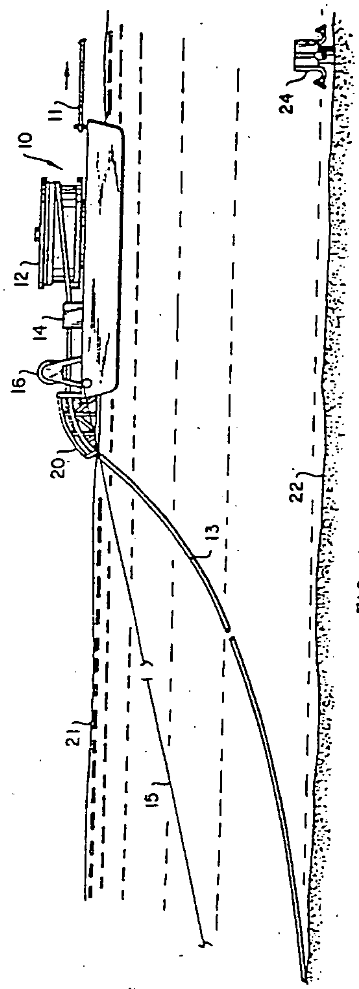

FIG. 4

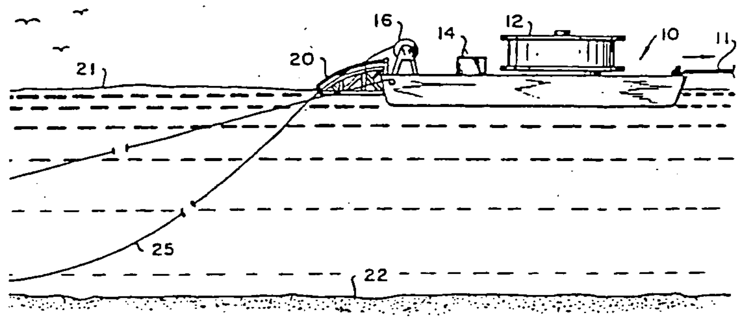

FIG. 5

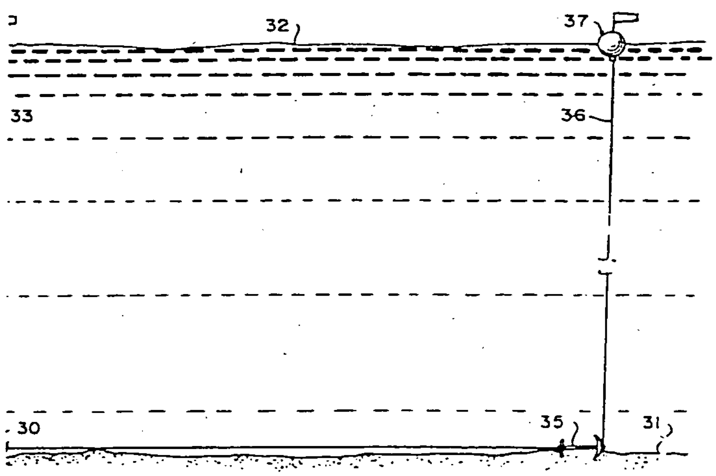

FIG 6

1107541 COMPLETE SPECIFICATION

7 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

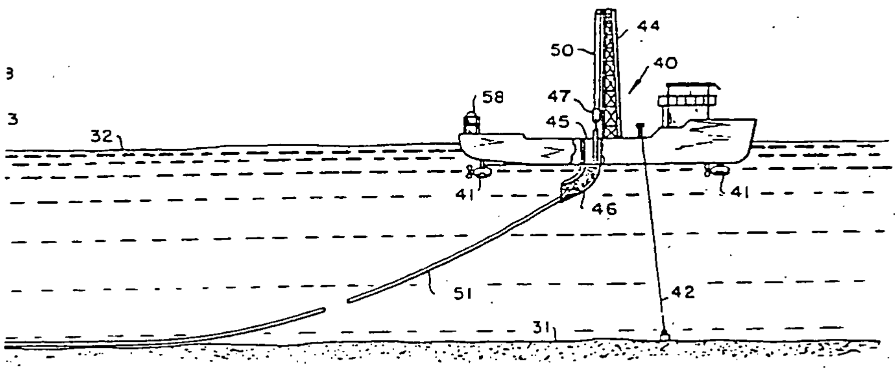

FIG. 7

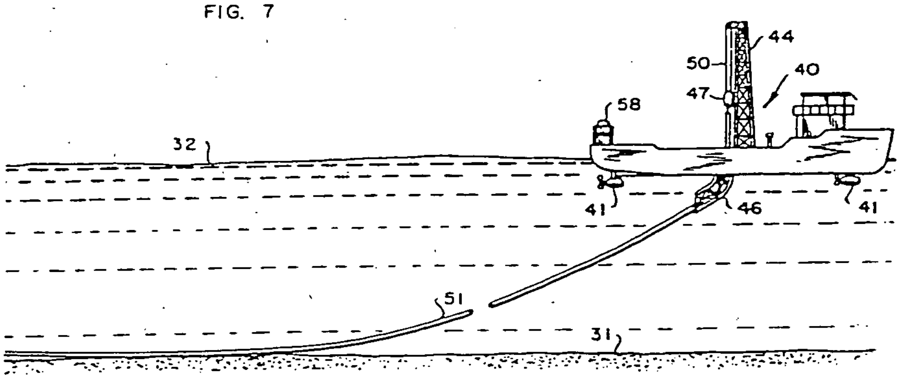

FIG. 8

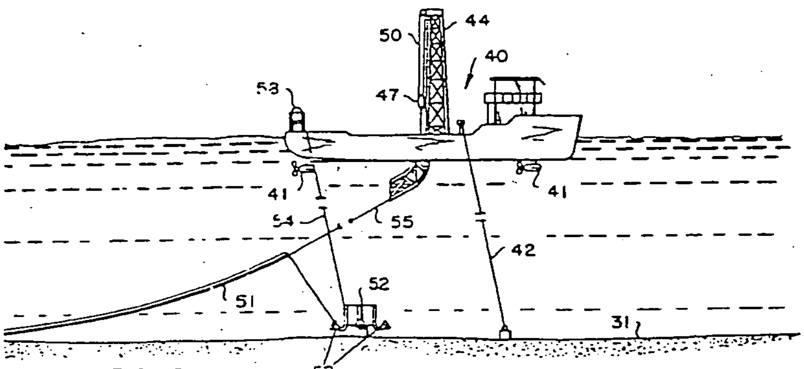

FIG. 9

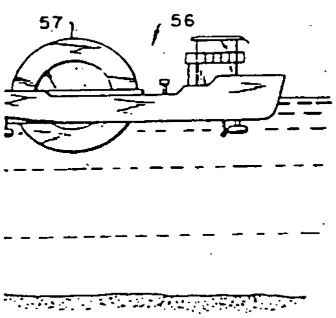

FIG. 11

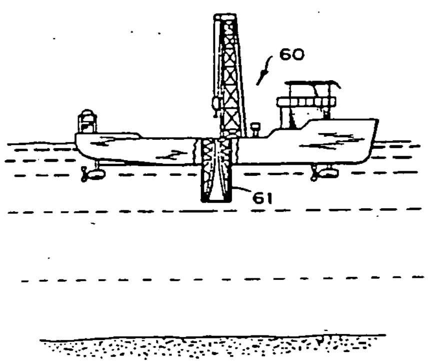

FIG. 12

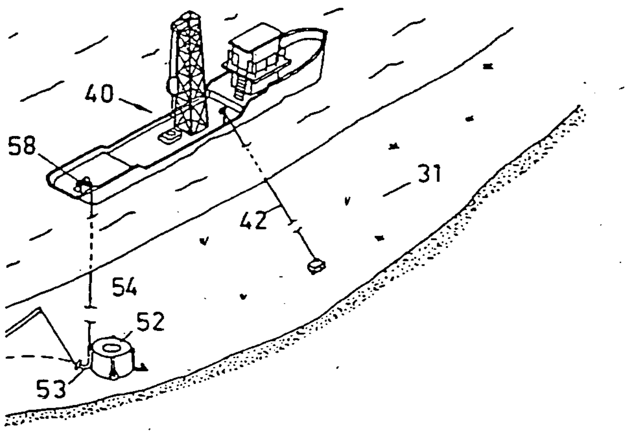

FIG. 10

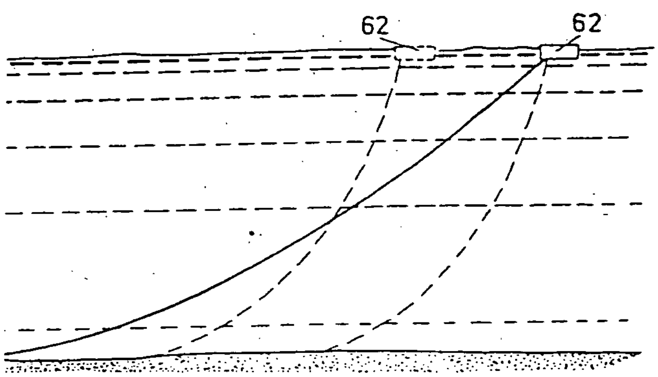

FIG. 14

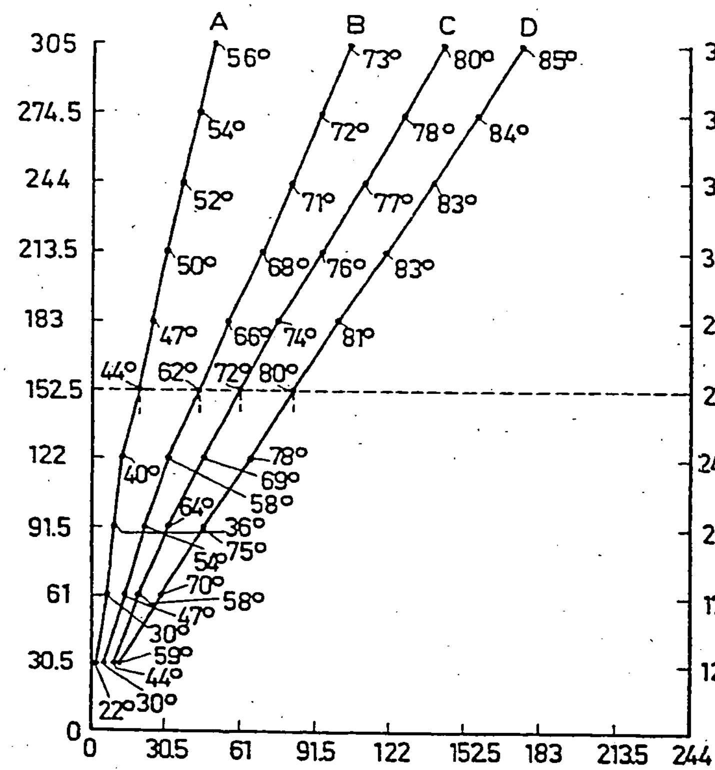
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FIG.13